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Literature Review: Effect of Impurities on the Compressive Strength of α and β Plutonium Metal

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Introduction

As part of the study on the effect of the plutonium α–β phase transition expansion on storage can integrity (Flamm et al., 1997; Spearing et al., 1999), an issue that needs to be addressed is the effect of impurities on the compressive yield strength of plutonium metal. The compressive yield strength of plutonium metal is one factor that may affect how much strain is imparted upon a stainless steel storage canister due to the volume expansion associated with the α–β phase transition. This report presents a brief review of the literature relevant to the effect of impurities on the compressive yield strength of plutonium metal, and summarizes what effect impurities may have on the outcome of experiments conducted thus far.

Literature Review

In general, the mechanical properties of Pu metal are well established (Gardner, 1980; Gardner and Mann, 1961). The compressive yield strength of plutonium metal as a function of temperature is given in Figure 1.

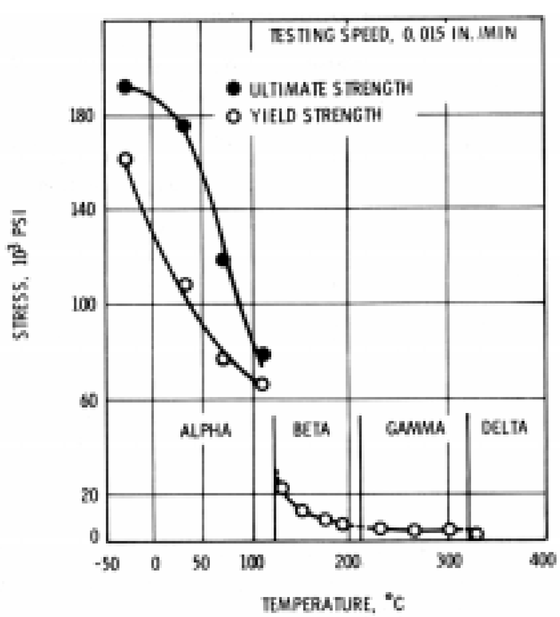

Figure 1 – Compressive Yield Strength of Pu as a Function of Temperature
(0.015 in/min testing speed)
From Gardner and Mann (1961).

However, the available literature on the topic of the effect of impurities on the compressive yield strength is sparse. Only two published studies could be found that directly address this issue, and are summarized below.

The effect of temperature, testing speed, and purity on the mechanical behavior of α-Pu in compression was investigated by Bronisz (1963). In this study, plutonium from two different sources was examined: one specimen was obtained from the standard calcium reduction technique and had a total impurity concentration of 480 ppm, and the other specimen was obtained via electrorefining with a total impurity concentration of 115 ppm. It was found that the yield strength of the electrorefined, higher purity, material is more dependent on the testing temperature than the yield strength of the calcium reduced, lower purity material. Furthermore, this effect becomes more pronounced as the strain rate increases. For temperatures in the region of interest with respect to the α–β Pu expansion experiments (> 100°C), the effect of impurities is to increase the compressive yield strength of α-Pu. A subset of the data presented by Bronisz (1963) is given in Figure 2.

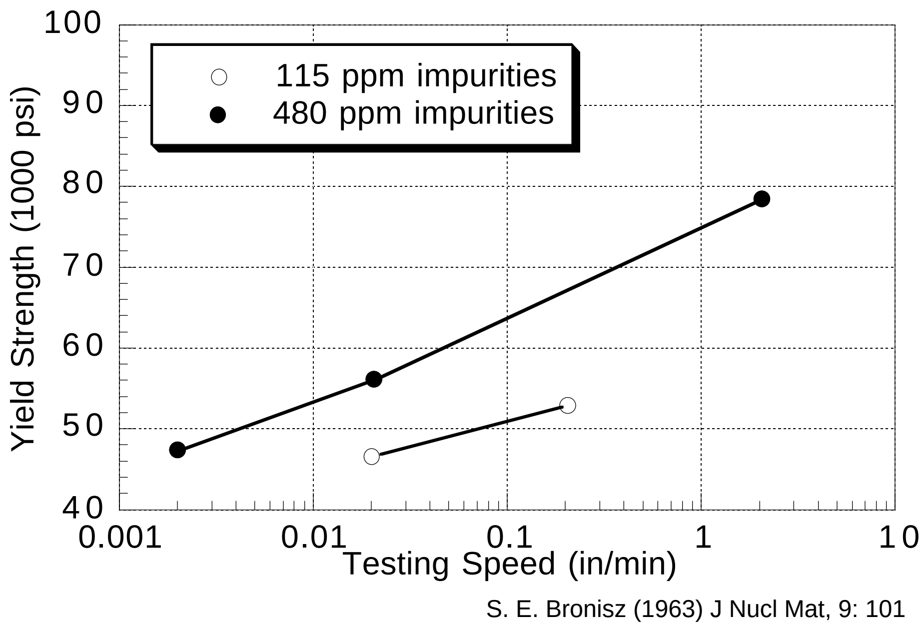

Figure 2 – Compressive Yield Strength vs. Testing Speed for α-Pu at 100°C

As is evident from the data in Figure 2, the sample with an impurity concentration of 480 ppm has a compressive yield strength approximately 20-25% greater than that of the electrorefined sample with an impurity concentration of 115 ppm. Bronisz (1963) concludes that the yield strength of α-Pu decreases as the testing temperature increases and that this effect is more pronounced for the purer material. Furthermore, plutonium with low impurity levels twins more easily than does plutonium with higher impurity levels. Thus, the reason for higher compressive yield strengths with increasing impurity levels may be due to pinning of defect sites and grain boundaries by the impurities.

The effect of impurities and testing speed on the compressive yield strength of β-Pu at 175°C was reported by Gardner and Mann (1961). In this study, two samples were examined with total impurity levels of 328 ppm and 1467 ppm, the results of which are shown in Figure 3.

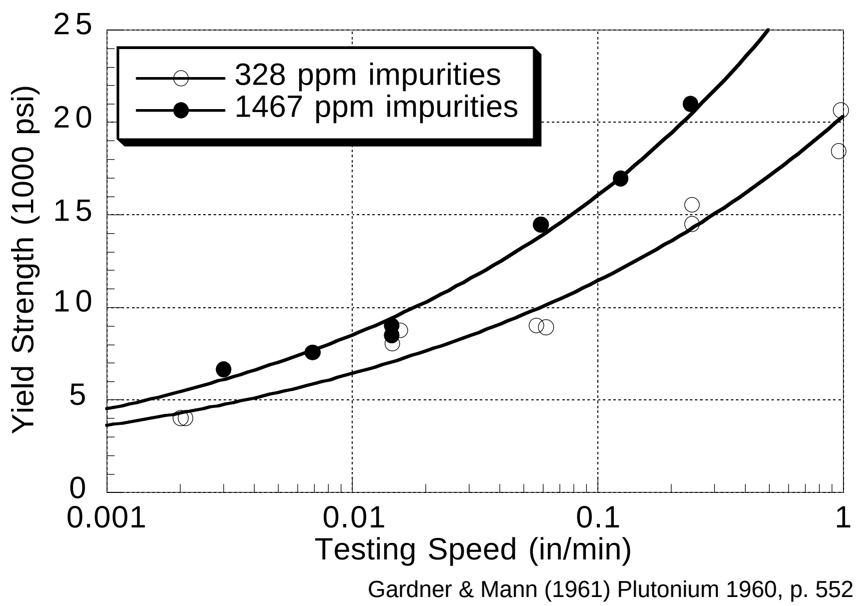

Figure 3 - Compressive Yield Strength vs. Testing Speed for β-Pu at 175°C

The effect of impurities on the compressive yield strength of β-Pu is similar to that for α-Pu: higher impurity concentrations increase the yield strength.

Discussion

Based on the above two studies, it is clear that the effect of increasing impurity concentrations in both α-Pu and β-Pu metal is to increase the compressive yield strength (for impurity concentrations up to 480 ppm in α-Pu and 1467 ppm in β-Pu). The range over which this effect is valid has not been established, nor has a comprehensive study been done on the compressive strength as a function of impurity concentration.

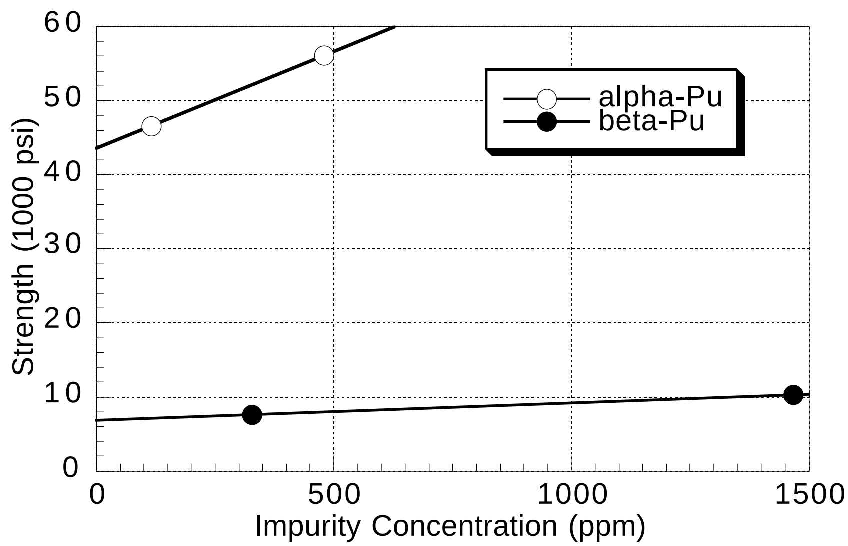

Figure 4 – Compressive Yield Strength vs. Impurity Concentration
(0.02 in/min testing speed)

Comparing the results summarized in Figure 2 with the published compressive yield strengths of Pu as a function of temperature given in Figure 1, it is apparent that the data for α-Pu are inconsistent. At 100°C and a testing speed of 0.015 in/min, Figure 1 (Gardner and Mann, 1961) shows a compressive yield strength of approximately 65,000 psi for α-Pu, while Figure 2 (Bronisz, 1963) shows a yield strength of 55,000 psi. If this discrepancy is due to impurities, then material used to generate the data presented in Figure 1 must have an impurity concentration greater than 480 ppm. The data for β-Pu are consistent between Figures 1 and 3. If we assume that the relationship between impurity concentration and yield strength is linear for a given testing speed, then we can predict what the yield strength would be for a given impurity concentration based on the limited data available (Figure 4). It is evident from Figure 4 that impurity concentration has a larger effect on the strength of α-Pu relative to β-Pu.

Conclusions and Relevance to Plutonium Metal Storage

Based on the limited available literature reviewed herein, the effect of increasing impurity concentrations in both α-Pu and β-Pu metal is to increase the compressive yield strengths. It is important to note that the compressive yield strength for high-purity α-Pu (46,000 – 53,000 psi) is well above the pressure of 2,033 psi as calculated by finite element analysis (Flanders, 1999) that the storage canister exerted upon the Pu ingot during the α–β phase transition during the experiment on storage canister integrity (Spearing et al., 1999). In contrast, the compressive yield strength at slow testing speeds of high-purity β-Pu near the β–γ phase transition (~4,000 psi) is much closer to this calculated pressure. At this point, there is no known relationship between the compressive yield strength of plutonium and the "effective yield strength" through the phase transition, as used by Flanders (1999).

Given that the commonly accepted yield strengths for Pu metal based on the values published by Gardner (1980) appear to be based on materials with impurity levels >500 ppm, these yield strengths should be sufficient for bounding the effects of metal expansion on storage can integrity for metals with similar or lower impurity levels.

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